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United States
Department of
Agriculture



Forest Service

Forest Health
Protection

Davis, CA

FSCBG/RT Real-Time Model Subroutines for Spray Cloud Prediction

FPM 95-9
July 1995

Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S. Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.



FPM 95-9
(C.D.I. Technical Note 94-20)
June 1995

**FSCBG/RT Real-Time Model
Subroutines for Spray Cloud
Prediction**

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1996-1997
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2002-2003

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| Year | 1994-1995 | 1996-1997 | 1998-1999 | 1999-2000 | 2000-2001 | 2001-2002 | 2002-2003 | 2003-2004 |
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SUMMARY

One of the most exciting areas of current aerial application technology is the use of global positioning (in particular, differential GPS) to provide a real-time image of the position of a spray aircraft during spray operation. Current hardware range from simple systems that keep track of the aircraft flight path (for later playback), to more sophisticated aircraft navigational systems that provide a means for the pilot to correct the aircraft flight path while spraying (continuous feedback). One addition anticipated to these systems is access to a very fast version of the USDA Forest Service aerial application prediction model FSCBG (Forest Service Cramer-Barry-Grim). This version of the model, FSCBG/RT (RT for Real Time) described herein, will run in real time on the on-board computer. It will access application rate, meteorological parameters, release height, and aircraft direction to make predictions of spray deposition and air concentration at selected receptor sites. The model includes the effects of aircraft speed, flight profile, pump pressure changes, flow rate, and other available data. Because simplifications have been made to the interpretation of the physics of the spray process to recover computations rapidly, model predictions will be approximate and bounding (therefore, FSCBG/RT is not a substitute for the full capabilities of FSCBG). When added to dose response information, these downwind dispersion predictions will enable the pilot to make spray decisions in real time. The end product will track the aircraft and visualize the pesticide spray deposition and movement as spraying occurs.

This report reviews the potential for a GPS/GIS tracking system in the aerial application of pesticides, summarizes the development of the FSCBG/RT model, and presents the computer subroutines available to recover the desired spray cloud prediction.

One of the main aims of the present study was to investigate the effects of a 12-week training programme on the physical and physiological characteristics of young elite athletes. The study was conducted in a laboratory setting and involved 12 male subjects, aged 18-22 years, who were selected based on their performance in national level competitions. The subjects were divided into two groups: a training group and a control group. The training group followed a structured 12-week programme that included cardiovascular, strength, and flexibility exercises. The control group did not participate in any training programme. The study measured various physical and physiological parameters, including maximum oxygen consumption ($\dot{V}O_{2max}$), heart rate, blood pressure, and muscle strength. The results showed that the training group experienced significant improvements in all measured parameters compared to the control group. Specifically, the training group showed a 15% increase in $\dot{V}O_{2max}$, a 10% increase in heart rate, a 5% increase in blood pressure, and a 20% increase in muscle strength. These findings suggest that a 12-week training programme can effectively improve the physical and physiological characteristics of young elite athletes.

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1. INTRODUCTION

Over the last twenty-five years the USDA Forest Service, in cooperation with the U. S. Army, has been pursuing the development of computer codes to predict the dispersion and deposition of aerially released material. The two current codes available are AGDISP (AGricultural DISPersal, in Bilanin et al. 1989) and FSCBG (Forest Service Cramer-Barry-Grim, in Teske et al. 1993). FSCBG predicts the transport and behavior of pesticide sprays released from aircraft, influenced by the aircraft wake and local atmospheric conditions, through downwind drift and deposition, to total accountancy and environmental fate. The AGDISP near-wake model solves a Lagrangian system of equations for the position and position variance of spray material released from each nozzle on the aircraft. The FSCBG far-wake model begins with the results of AGDISP at the top of a canopy or near the ground, and solves a Gaussian diffusion equation to recover ground deposition. FSCBG includes an analytic dispersion model for multiple line sources oriented in any direction to the wind, an evaporation model for volatile spray components, a canopy penetration model for forest canopy interception, and an accountancy model to recover environmental fate of the released material.

The FSCBG solution procedure is as follows. Drop size distributions give the mass distribution of material as the spray is atomized by each nozzle. Drops containing volatile materials (water) begin to evaporate immediately upon entering the atmosphere, with the local temperature, relative humidity and wind speed determining the evaporation rate. The presence of the aircraft wake (with its vortical structure) may move material to unanticipated locations. Ambient winds superimpose additional horizontal velocity vectors on the spray material. Canopy deposition removes some of the spray material from the air and prevents some nonvolatile spray material from reaching the ground. Every aspect of the spray process is affected by the size and significance of atmospheric and aircraft-generated turbulence. Near-wake calculations follow the behavior of released spray near the aircraft, and when out of wake influence or at the top of the canopy, hand off to the dispersion calculations at user-designated downwind locations.

This solution procedure is programmed into FSCBG, a model that runs in reasonable time on personal computers. With the recent interest in differential GPS/GIS (Teske, Barry and Thistle 1994), there is an operational need to develop a faster version of FSCBG that can be accessed on the spray aircraft to predict spray cloud behavior in real time. The development of this version of FSCBG, called FSCBG/RT (for Real Time), forms the subject of this report.

2. GLOBAL POSITIONING SYSTEMS

Global positioning (GPS) is the enabling technology for recovering aircraft position in real-time. The following overview is drawn from Thistle, Jasumback and Kilroy (1994).

Over the last five years the U. S. Department of Defense (DOD) has been building and deploying a constellation of satellites to support military operations worldwide. The full complement of 24 satellites was not in place until 1993. For security reasons DOD implemented a policy of selective availability (SA), where the satellite signal is intentionally degraded so that the global positioning (GPS) available to the civilian community has an accuracy of better than 100 m in horizontal positioning 95 percent of the time, as opposed to on the order of 10 m for the military. SA is achieved by purposely affecting the signal timing (dither), introducing a fluctuating error in the indicated position. Thus, using the raw GPS signal, a civilian recipient would not know exactly how far from an absolute position the indicated position actually is at any given time.

The civilian community responded to SA by developing a differential system that eliminates the SA error and increases positional accuracy down to 2 to 5 m. This step is accomplished by placing one receiver at a ground point of known location, and, from its data, the range corrections necessary to make the receiver's GPS signal location coincide with the known location of the point are calculated. These corrections are then applied to the data from other receivers. This technique is known as differential GPS (DGPS), and can be done in real time or in post processing.

The present state of the art allows a GPS signal to be received at 5 Hz. This signal is used to guide the pilot along a desired flight path using a light bar, and is stored with absolute accuracy of 5 m or better. It can be transmitted back to the ground and input as an overlay into geographic information systems (GIS), so that an operations manager can actually observe the application in real time on a computer screen. The GIS capability is also valuable in analyzing coverage and efficiency, as the record of the operation can be downloaded and input as a spatial overlay into the GIS database, from which spatial summary statistics can then be computed. The current technology also provides an alarm for the pilot when an edge is crossed, and lights to indicate when a specific ground location is below the aircraft. The signals could be used in a control mode to perform spray on/off functions based on position, and make drift predictions in real-time, thereby alerting applicators and operation managers to changes in field conditions during application which raise the risk of off-target drift of pesticides. The alarm and other warning indicators can also be monitored by other aerial or ground stations.

Over the past three years these technologies have begun to favorably impact the agricultural aviation industry. The immediate cost savings and reduction in human exposure realized by the elimination of human flagmen, and other marking methods, makes this technology very attractive. Of great interest to the USDA Forest Service, Forest Pest Management (FPM), is the ability to know accurately and to log exactly the position of an aerial spray system during an application event. This ability can eliminate the problem of treating the wrong area, making flagmen and block marking unnecessary in most cases. Questions raised in litigation can be directly addressed with detailed records. Lost pilot time due to finding the treatment block and home base can be reduced, costs associated with returning to base for reloading and then returning to the

exact position application ceased can be reduced, and misses or gaps can be spotted immediately by the applicator or operations manager, allowing corrective action to be taken quickly. In general, costs can be lowered, safety improved and efficiency increased if GPS navigation systems were integrated into FPM pesticide application operations.

Previous field studies (Barry 1977; Richardson et al. 1993; Ghent and Twardus 1994; Mierzejewski, Buzzard and Laudermilch 1994; Kilroy and Thistle 1994) point to a need for these devices. Field results from the use of these devices, either operationally or demonstration (in Washington, Michigan, Arizona, Pennsylvania, Virginia, West Virginia, North Carolina and Arkansas to date), have ranged from disappointing to impressive. Because it is expected that GPS navigation technology will impact FPM operations in the near future, a field demonstration was deemed desirable. Such a test was conducted in mid-October 1994 in Montana by the USDA Forest Service, Missoula Technology and Development Center, and FPM staff. Preliminary results (Thistle et al. 1994) have been released, with a final report due later in 1995.

3. MODEL CONSIDERATIONS

The Gaussian algorithm in FSCBG may be configured to provide an interactive response to continuous inputs from a positioning device. This step would be necessary to provide the pilot (and/or ground monitor) with the anticipated deposition pattern of the spray material during spraying. The positioning device would send to the computer model the present coordinates, elevation, and direction of the aircraft, along with the present meteorological conditions. Specific sensitive areas downwind could then be monitored in real time with regard to the anticipated level of released spray material reaching them.

The primary requirement for such a model is the need to make its prediction in real time. Immediacy demands a simple model, which nonetheless must provide correct information in this context.

To develop such a model, here denoted FSCBG/RT (for Real Time response), the approach taken is the following (with nomenclature summarized in Table 1). The spray aircraft flies a flight path as shown in Figure 1 (it need not be a straight line in this analysis). The wind provides a preferential direction along which the released spray material travels. If the aircraft is at height H , the traditional Gaussian point source approach (Turner 1994), with no surface reflection and no correction for virtual origin, would give the instantaneous concentration C from a point on the aircraft flight path to any downwind receptor location as:

$$C = \frac{Q}{2 \pi u \sigma_y \sigma_z} \exp \left[-\frac{y^2}{2 \sigma_y^2} \right] \exp \left[-\frac{H^2}{2 \sigma_z^2} \right] \quad (1)$$

Spray material released through nozzles atomizes into a drop size distribution. To account for the contribution from each drop size, Eq 1 can be generalized with the slanted plume approximation (Teske et al. 1993) to give:

$$C = \frac{Q}{2 \pi u \sigma_y \sigma_z} \exp \left[-\frac{y^2}{2 \sigma_y^2} \right] \sum_{i=1}^N f_i \exp \left[-\frac{(H - v_i x / u)^2}{2 \sigma_z^2} \right] \quad (2)$$

where the summation is over all drops N in the drop size distribution, and the effect of drop size comes primarily through the settling velocity.

The incremental deposition (the deposition occurring over the time interval Δt) may also be developed (Teske 1992) to give, within the same above simplifications:

$$D = \frac{Q \Delta t H}{2 \pi \sigma_y \sigma_z x} \exp \left[-\frac{y^2}{2 \sigma_y^2} \right] \sum_{i=1}^N f_i \exp \left[-\frac{(H - v_i x / u)^2}{2 \sigma_z^2} \right] \quad (3)$$

Typically, σ_y is related to σ_h through the simple expression $\sigma_y = \sigma_h x$, and $\sigma_z = \sigma_y / 3$. Thus, with the source strength, release height, wind speed and direction, azimuthal standard deviation, and drop size distribution known, the instantaneous concentration and incremental deposition at any location downwind of the instantaneous location of the spray aircraft may be determined. The positioning device would supply this information in real time, with the source strength known by the tank flow rate.

Instantaneous concentration behavior with downwind distance may be found by examining the plume centerline ($y = 0$) concentration with $v_i = 0$, defining $X = \frac{x \sigma_h}{3 H}$ and rewriting Eq 2 as:

$$\frac{6 \pi u H^2 C}{Q} = \frac{1}{X^2} \exp \left[-\frac{1}{2 X^2} \right] \quad (4)$$

This equation is plotted in Figure 2, where it may be seen that instantaneous concentration is readily recoverable from downwind distance. The peak normalized concentration is 0.736, occurring at $X = 0.707$.

Incremental deposition behavior with downwind distance may likewise be determined by rewriting Eq 3 as:

$$\frac{18 \pi H^2 D}{Q \Delta t \sigma_h} = \frac{1}{X^3} \exp \left[-\frac{1}{2 X^2} \right] \quad (5)$$

This equation is plotted in Figure 3, where it may be seen that incremental deposition is readily recoverable from downwind distance as well (each computed time interval adds to the deposition at the desired receptor locations). The peak normalized deposition is 1.159, occurring at $X = 0.577$. The half-peak values, used to define the deposition swath width, occur at $X = 0.978$ and $X = 2.622$. In this special case the swath width may be found from $\Delta x_{sw} = 4.932 H / \sigma_h$.

To estimate the average settling velocity for each drop size category, an estimate must be made of the amount of material evaporated during spraying. The approach is to examine each drop size in the atomization at the nozzle by the algorithm suggested in Trayford and Welch (1977):

$$1 - \left(\frac{D_i}{D_{io}} \right)^2 = 84.76 \left[\frac{t \Delta T}{D_{io}^2} \right] \quad (6)$$

The wet bulb temperature depression ΔT is commonly obtained from the Carrier equation (Jennings and Lewis 1950). The release height and settling velocity for each drop size recover the anticipated fall time $t = H / v_i$, for use in Eq 6. The final diameter D_i is used to recompute the settling velocity, and find the average between the initial and final values for use in Eqs 2 and 3.

This extremely simple (and hence fast) model FSCBG/RT should provide real-time response as the pilot is spraying. The downwind concentrations and depositions would be monitored continuously, achieving significant potential benefit for off-target drift detection (besides the obvious one of recording the actual flight paths flown). Once in place, and appropriately interfaced, the model will provide ,limited predictive response needed in the field to evaluate a spray project while in operation.

Caution should be exercised with the model presented here, as it has not yet received field trial validation. Significant simplifications have occurred in moving from the full FSCBG model equations (found in Teske et al. 1993) to Eqs 2 and 3. FSCBG/RT should be seen as a bounding or approximate prediction that will provide guidance to the pilot when concentration or deposition limits are approached.

Table 1. FSCBG/RT Model Nomenclature.

| Symbol | Definition | Units |
|-----------------|---|-----------------|
| C | Instantaneous concentration | gm/m^3 |
| D | Incremental deposition in Δt | gm/m^2 |
| D_i | Evaporated drop diameter for drop size category i | micrometers |
| D_{i0} | Initial drop diameter for drop size category i | micrometers |
| f_i | Mass fraction for drop size category i | - |
| H | Aircraft height | m |
| N | Number of drop size categories | - |
| Q | Source strength of active material per unit time | gm/sec |
| t | Time | sec |
| u | Average wind speed | m/sec |
| v_i | Settling velocity for drop size category i | m/sec |
| x | Distance parallel to the wind direction | m |
| y | Distance normal to the wind direction | m |
| Δt | Time interval | sec |
| ΔT | Wet bulb temperature depression | deg C |
| Δx_{sw} | Swath width | m |
| σ_h | Azimuthal standard deviation | radians |
| σ_y | Horizontal standard deviation | m |
| σ_z | Vertical standard deviation | m |

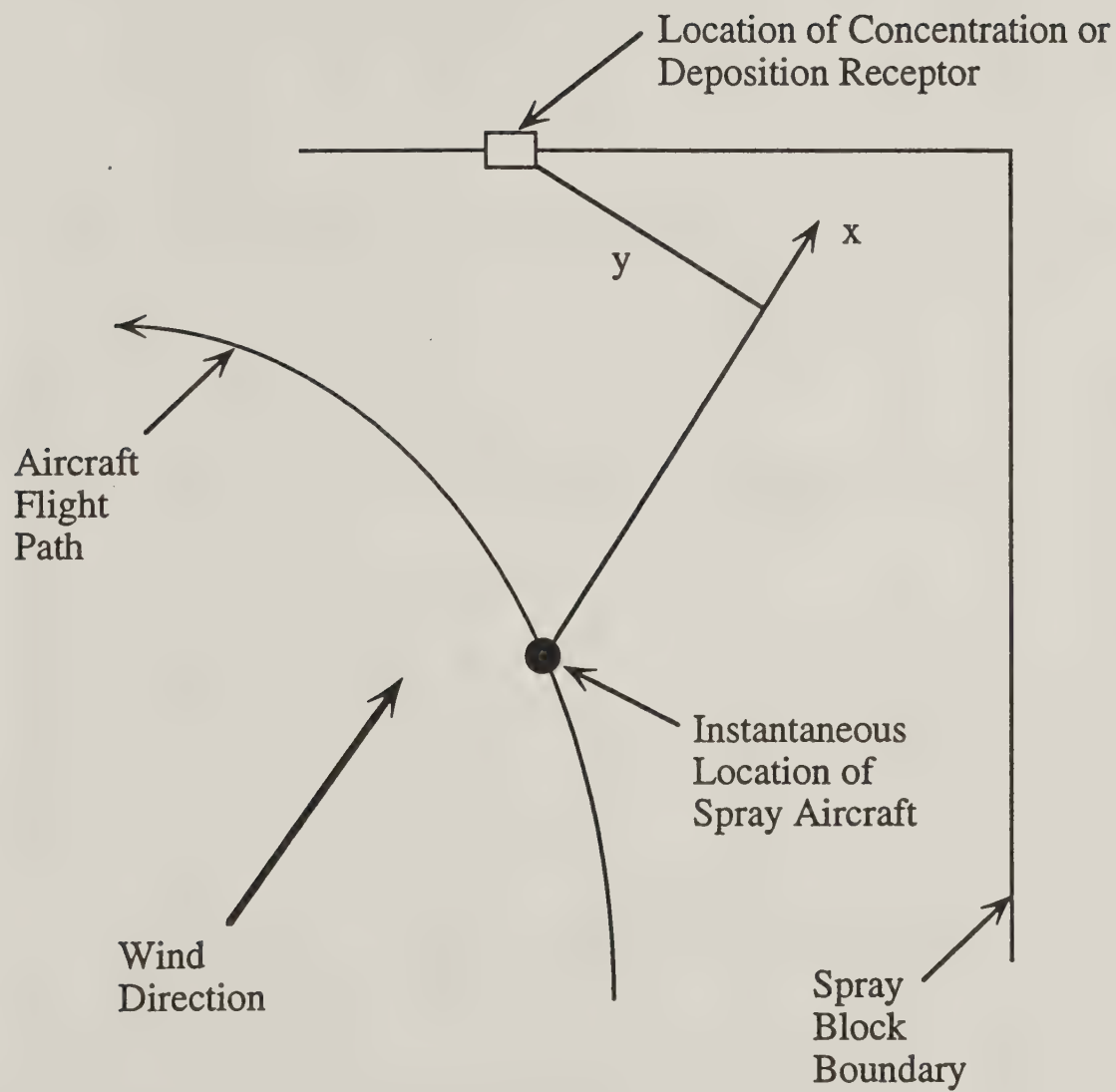


Figure 1. Schematic of FSCBG/RT solution geometry.

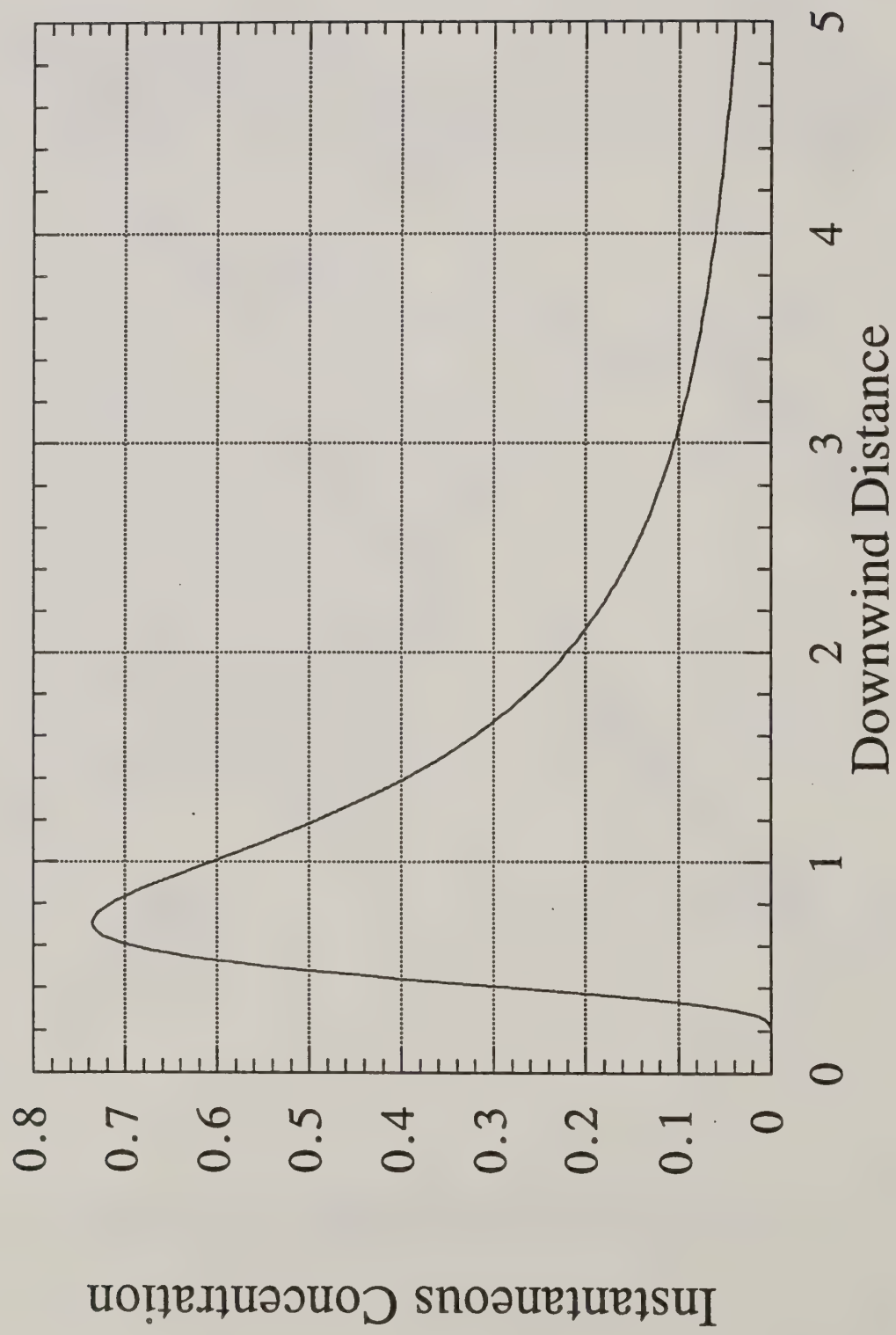


Figure 2. Normalized instantaneous centerline concentration downwind of a point source release.

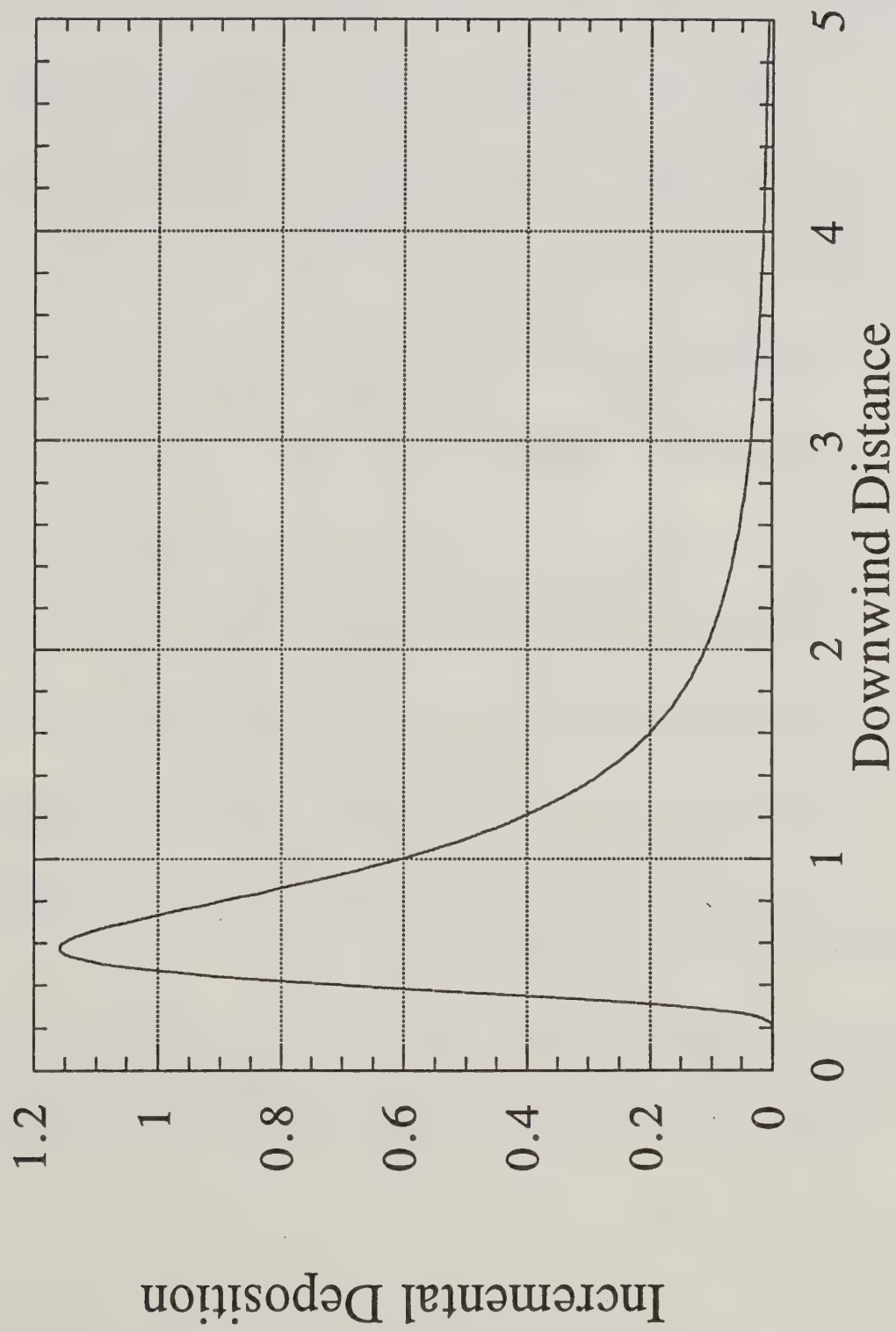


Figure 3. Normalized incremental centerline deposition downwind of a point source release.

4. SAMPLE CALCULATION

To provide a quantitative feel for the application of FSCBG/RT, the separate computational blocks have been programmed into a Zenith Z-Note 425Ln+, a full 486 machine (portable) operating at 25 mHz. Data conversion times from an on-board GPS system are not included in the following estimates. The separate computations break down as follows:

1. Meteorological measurements assume a ten-second (ten data points) stream of data at 1 Hz, updated every second by dropping the oldest data point and replacing it with the newest. Each flight line will typically be completed within a minute or two, and wind direction correction must occur rapidly; thus, a short averaging time (rather than the more typical ten-minute averaging time) is assumed. Computation of the average wind speed and direction, and the azimuthal standard deviation, takes 0.06 sec to initialize, and 3.62 msec per update.
2. Computation of the average release height, temperature and relative humidity assume a one-minute (six data points) stream of data at 0.1 Hz, updated every ten seconds by dropping the oldest data point and replacing it with the newest. Release height, temperature and relative humidity should be quite insensitive along a flight line. This approach takes 0.06 sec to initialize, and 3.46 msec per update.
3. The average temperature and relative humidity are used to compute the wet bulb temperature depression, all feeding into Eq 6 and the determination of the average settling velocity for each drop size category. For a typical nozzle D8-46 with 24 drop size categories (Skyler and Barry 1991), and a temperature of 20 deg C and 80 percent relative humidity, this procedure requires 5.50 msec.
4. The predicted instantaneous concentration at a single downwind location (off the plume centerline) is found from Eq 2 in 1.31 msec.
5. The predicted incremental deposition at a single downwind location (off the plume centerline) is found from Eq 3 in 1.26 msec.

Thus, after initialization (which can be done before spraying begins), the total update computation per second takes 15.15 msec for one receptor location, and 2.57 msec for each additional receptor location.

The proposed approach is quite simple, and includes well-established computational techniques. However, each of the computations outlined above do not need to be done in a continuous manner. Rather, they may be done intermittently throughout the entire spray project (some may even be done in a turn, queued to flow rate off). The load on a real-time positioning device is therefore judged to be minimal.

5. CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the advantages of an operational on-board GPS/GIS real-time positioning device in the aerial application of pesticides, and proposes the FSCBG/RT model for qualitatively predicting concentration and deposition at selected locations during spraying. The locations may be either areas where drift is to be avoided or spray target areas. The subroutines that comprise FSCBG/RT are available at no charge to all developers of real-time positioning devices, with the hope that the approach discussed here becomes a first step toward a fully-integrated drift sensing tool.

What remains to be done is to test the validity of the developed equations in a field trial, and compare predictions of FSCBG/RT with the full FSCBG code. Since the equations have approximated the physics of the aerial spray process, with an eye toward reducing the computer time involved, a field trial would help scale the bounding predictions made by the simplified equations. Therefore, it seems reasonable to suggest a simple field trial to validate the proposed real-time simulation approach. These validation trials should then be followed by a real-time demonstration with a prototype GPS system, perhaps funded by a partnership of public and private organizations interested in developing (and implementing) such a system.

6. FORTRAN SUBROUTINE DETAILS

Table 2 lists the source code for the various subroutines in FSCBG/RT. They are detailed as follows:

Subroutine WINDS

Subroutine WINDS takes as input the wind speed and direction on one-second (1 Hz) intervals, collecting ten data points (ten seconds of data), then averaging over the ten seconds using the unit circle algorithm developed by Haugen (1963). As additional data are received by the subroutine, the oldest data points are discarded. Data are stored in common block SAVE_S. Results are sent back to the calling program through the common block RTWIND, containing the average wind speed, wind direction and azimuthal standard deviation. The coordinate system assumed in FSCBG/RT is a coordinate system with the x direction pointing East and the y direction pointing North. The wind direction is assumed to be the direction from which the wind is blowing.

Subroutine TEMPS

Subroutine TEMPS takes as input the release height, temperature and relative humidity on ten-second (0.1 Hz) intervals, collecting six data points (one minute of data), then averaging over the minute. As additional data are received by the subroutine, the oldest data points are discarded. Data are stored in common block SAVE_T. Results are sent back to the calling program through the common block RTTEMP, containing the average release height, temperature and relative humidity.

Subroutine MASSS

Subroutine MASSS takes as input the drop size distribution for the nozzles and spray material on the spray aircraft, along with the average release height, temperature and relative humidity determined from subroutine TEMPS. The wet bulb temperature depression is found in the function WETB programming the Carrier equation (Jennings and Lewis 1950). Saturated pressure values are obtained from the function FPRES programming the water saturation line (Meyer et al. 1979). Each drop size category is assumed to fall vertically at its settling velocity, determined by the approximation of Best (1950) in the function VTERM. Equation 6 is then solved for each drop size, and the average settling velocity is computed for all drop size categories, and stored in common block RTMASS.

Subroutine CONCS

Subroutine CONCS takes as input the location of the spray aircraft and the point at which the instantaneous concentration is desired, the active material flow rate and the average settling velocities, along with the average wind speed and direction, azimuthal standard deviation and average release height. The downwind and crosswind locations are determined by trigonometric functions, and Eq 2 is solved for the answer. The resulting concentration is the anticipated instantaneous concentration at the receptor location for the instantaneous location of the aircraft.

Subroutine DEPOS

Subroutine DEPOS takes as input the location of the spray aircraft and the point at which the incremental deposition is desired, the active material released in the time interval and the average settling velocities, along with the average wind speed and direction, azimuthal standard deviation and average release height. The downwind and crosswind locations are determined by trigonometric functions, and Eq 3 is solved for the answer. The resulting deposition is the anticipated incremental deposition at the receptor location for the time interval represented along the aircraft flight path. All incremental deposition values must be summed to produce the total deposition predicted at the receptor location.

Table 2. FSCBG/RT Source Code.

```

C**WINDS
      SUBROUTINE WINDS(XSPD,XDIR)
C
C Subroutine WINDS accepts wind speed and direction data on one-second
C intervals, averages them over ten seconds of data (10 entries), and
C updates the entries continuously (dropping the oldest values)
C
C Inputs:
C XSPD - Wind speed (m/sec)
C XDIR - Wind direction (rad)
C
C Outputs:
C SPEED - Ten-second average wind speed (m/sec)
C DIREC - Ten-second average wind direction (rad)
C AZMTH - Azimuthal standard deviation (rad)
C
      COMMON /SAVE_S/ NPTS,NSTS,SPD(10),SDR(10),CDR(10)
      COMMON /SAVE_S/ SPDR,YBAR,XBAR
      COMMON /RTWIND/ SPEED,DIREC,AZMTH
C
      DATA NPTS,NSTS,NMAX / 0,1,10 /
      DATA SPDR,YBAR,XBAR / 3*0.0 /
C
      NPTS=NPTS+1
      IF (NPTS.GT.NMAX) THEN
        NPTS=NPTS-NMAX
        NSTS=0
      ENDIF
C
      IF (NSTS.EQ.0) THEN
        SPDR=SPDR-SPD(NPTS)
        YBAR=YBAR-SDR(NPTS)
        XBAR=XBAR-CDR(NPTS)
      ENDIF
C
      SPD(NPTS)=XSPD
      SDR(NPTS)=SIN(XDIR)
      CDR(NPTS)=COS(XDIR)
      SPDR=SPDR+SPD(NPTS)
      YBAR=YBAR+SDR(NPTS)
      XBAR=XBAR+CDR(NPTS)
C
      SPEED=SPDR/NMAX
      TEMY=YBAR/NMAX
      TEMX=XBAR/NMAX
      DIREC=ATAN2(TEMY,TEMX)
      TEM=AMIN1(1.0,AMAX1(-1.0,1.0-TEMX*TEMX-TEMY*TEMY))
      AZMTH=ASIN(SQRT(TEM))
      RETURN
      END

```

Table 2. FSCBG/RT Source Code (continued).

```

C**TEMPS
      SUBROUTINE TEMPS (XHT,XTP,XRH)
C
C  Subroutine TEMPS accepts release height, temperature and relative
C  humidity data on ten-second intervals, averages them over one
C  minute of data (6 entries), and updates the entries continuously
C  (dropping the oldest values)
C
C  Inputs:
C  XHT      - Release height (m)
C  XTP      - Temperature (deg C)
C  XRH      - Relative humidity (percent)
C
C  Outputs:
C  HEIGHT   - One-minute average release height (m)
C  TEMPR    - One-minute average temperature (deg C)
C  RHUMD    - One-minute average relative humidity (percent)
C
      COMMON /SAVE_T/ NPTT,NSTT,HIGH(6),TEMP(6),RHUM(6)
      COMMON /SAVE_T/ SHIGH,STEMP,SRHUM
      COMMON /RTTEMP/ HEIGHT,TEMPR,RHUMD
C
      DATA NPTT,NSTT,NMAX / 0,1,6 /
      DATA SHIGH,STEMP,SRHUM / 3*0.0 /
C
      NPTT=NPTT+1
      IF (NPTT.GT.NMAX) THEN
        NPTT=NPTT-NMAX
        NSTT=0
      ENDIF
C
      IF (NSTT.EQ.0) THEN
        SHIGH=SHIGH-HIGH(NPTT)
        STEMP=STEMP-TEMP(NPTT)
        SRHUM=SRHUM-RHUM(NPTT)
      ENDIF
C
      HIGH(NPTT)=XHT
      TEMP(NPTT)=XTP
      RHUM(NPTT)=XRH
      SHIGH=SHIGH+HIGH(NPTT)
      STEMP=STEMP+TEMP(NPTT)
      SRHUM=SRHUM+RHUM(NPTT)
C
      HEIGHT=SHIGH/NMAX
      TEMPR=STEMP/NMAX
      RHUMD=SRHUM/NMAX
      RETURN
      END

```

Table 2. FSCBG/RT Source Code (continued).

```

C**MASSS
  SUBROUTINE MASSS
C
C Subroutine MASSS uses the average height, temperature and relative
C humidity to evaporate the mass fraction of the released material
C and compute the average terminal velocity for each drop size
C
C Inputs:
C HEIGHT - Average release height (m)
C TEMPR - Average temperature (deg C)
C RHUMD - Average relative humidity (percent)
C NDROP - Number of drop sizes in the drop size distribution
C XDIAM - Array containing the drop diameters (micrometers)
C XFRAC - Array containing the mass fractions (totaling 1.0)
C
C Output:
C XTERM - Array containing average terminal velocities (m/sec)
C
  COMMON /RTTEMP/ HEIGHT, TEMPR, RHUMD
  COMMON /RTMASS/ NDROP, XDIAM(100), XFRAC(100), XTERM(100)
C
  DTEMP=WETB(TEMPR, RHUMD, 1013.0)
  DO 10 N=1, NDROP
    VSI=VTERM(0.0005*XDIAM(N))
    TIME=HEIGHT/VSI
    TEM=84.76*TIME*DTEMP/XDIAM(N)/XDIAM(N)
    DFRAC=SQRT(1.0-AMIN1(1.0, TEM))
    VSF=VTERM(0.0005*XDIAM(N)*DFRAC)
    XTERM(N)=0.5*(VSI+VSF)
10  CONTINUE
  RETURN
  END

```

Table 2. FSCBG/RT Source Code (continued).

```

C**WETB
      FUNCTION WETB(TMPR,RHUM,PRES)
C
C  Function WETB computes the wet bulb temperature depression
C
C  Inputs:
C  TMPR    - Temperature (deg C)
C  RHUM    - Relative humidity (percent)
C  PRES    - Ambient pressure (mb)
C
C  Output:
C  WETB    - Wet bulb temperature depression (deg C)
C
      TDRY=1.8*TMPR+32.0
      PAMB=14.7*PRES/1013.0
C
      PDRY=FPRES(TDRY)
      PSAT=0.01*RHUM*PDRY
      TMIN=32.0
      TMAX=TDRY
      ITER=0
C
10    TEMP=0.5*(TMIN+TMAX)
      ITER=ITER+1
      PTEM=FPRES(TEMP)
      PNEW=PTEM-(PAMB-PTEM)*(TDRY-TEMP)/(2800.0-1.3*TEMP)
      IF (ABS(PNEW-PSAT).LT.0.001.OR.ITER.GT.20) GO TO 20
      IF (PNEW.LT.PSAT) THEN
        TMIN=TEMP
      ELSE
        TMAX=TEMP
      END IF
      GO TO 10
C
20    WETB=(TDRY-TEMP)/1.8
      RETURN
      END

```

Table 2. FSCBG/RT Source Code (continued).

```

C**FPRES
  FUNCTION FPRES (TMPR)
C
C  Function FPRES evaluates the saturated pressure
C
C  Input:
C  TMPR    - Temperature (deg F)
C
C  Output:
C  FPRES   - Pressure (psia)
C
    THETA=(TMPR+459.67)/1165.14
    OMT=1.0-THETA
    SUMT=-OMT*(7.691234564+OMT*(26.08023696+OMT*
$   (168.1706546+OMT*(-64.23285504+OMT*118.9646225))))
    SUMT=SUMT/THETA/(1.0+OMT*(4.16711732+OMT*
$   20.9750676))-OMT/(OMT*OMT*1.0E+09+6.0)
    FPRES=EXP (SUMT) *3208.235
    RETURN
  END

```

Table 2. FSCBG/RT Source Code (continued).

```
C**VTERM
      FUNCTION VTERM(RADIUS)
C
C  Function VTERM computes the terminal velocity
C
C  Input:
C  RADIUS - Drop radius (mm)
C
C  Output:
C  VTERM - Terminal velocity (m/sec)
C
      VTERM=9.58*(1.0-EXP(-(RADIUS/0.885)**1.147))
      RETURN
      END
```

Table 2. FSCBG/RT Source Code (continued).

```

C**CONCS
      SUBROUTINE CONCS (XPL,YPL,XPT,YPT,Q,XCONC)
C
C  Subroutine CONCS computes the instantaneous concentration
C  at the specified point
C
C  Inputs:
C  SPEED  - Average wind speed (m/sec)
C  DIREC  - Direction from which the wind is blowing (rad)
C  AZMTH  - Average azimuthal standard deviation (rad)
C  HEIGHT - Average release height (m)
C  XPL    - X point of release (m)
C  YPL    - Y point of release (m)
C  XPT    - X point of interest (m)
C  YPT    - Y point of interest (m)
C  Q      - Flow rate (gm/sec)
C  XFRAC  - Array containing the mass fractions (totaling 1.0)
C  XTERM  - Array containing average terminal velocities (m/sec)
C
C  Output:
C  XCONC  - Instantaneous concentration (gm/cu m)
C
      COMMON /RTWIND/ SPEED,DIREC,AZMTH
      COMMON /RTTEMP/ HEIGHT,TEMPR,RHUMD
      COMMON /RTMASS/ NDROP,XDIAM(100),XFRAC(100),XTERM(100)
C
      TDIR=DIREC+3.14159
      X=(XPT-XPL)*SIN(TDIR)+(YPT-YPL)*COS(TDIR)
      Y=(XPT-XPL)*COS(TDIR)-(YPT-YPL)*SIN(TDIR)
C
      IF (X.GT.0.0) THEN
        TEMY=EXP(-0.5*(Y/AZMTH/X)**2)
        XTOTZ=0.0
        DO 10 N=1,NDROP
          TEMZ=EXP(-0.5*(3.0*(HEIGHT-XTERM(N)*X/SPEED)/AZMTH/X)**2)
          XTOTZ=XTOTZ+XFRAC(N)*TEMZ
10      CONTINUE
        XCONC=Q*TEMY*XTOTZ/(2.0944*SPEED*AZMTH*AZMTH*X*X)
      ELSE
        XCONC=0.0
      ENDIF
      RETURN
      END

```

Table 2. FSCBG/RT Source Code (concluded).

```

C**DEPOS
      SUBROUTINE DEPOS (XPL,YPL,XPT,YPT,QDT,XDEPO)
C
C  Subroutine DEPOS computes the incremental deposition
C  at the specified point
C
C  Inputs:
C  SPEED   - Average wind speed (m/sec)
C  DIREC   - Direction from which the wind is blowing (rad)
C  AZMTH   - Average azimuthal standard deviation (rad)
C  HEIGHT  - Average release height (m)
C  XPL     - X point of release (m)
C  YPL     - Y point of release (m)
C  XPT     - X point of interest (m)
C  YPT     - Y point of interest (m)
C  QDT     - Material released in time increment (gm)
C  XFRAC   - Array containing the mass fractions (totaling 1.0)
C  XTERM   - Array containing average terminal velocities (m/sec)
C
C  Output:
C  XDEPO   - Incremental deposition (gm/sq m)
C
      COMMON /RTWIND/ SPEED,DIREC,AZMTH
      COMMON /RTTEMP/ HEIGHT,TEMPR,RHUMD
      COMMON /RTMASS/ NDROP,XDIAM(100),XFRAC(100),XTERM(100)
C
      TDIR=DIREC+3.14159
      X=(XPT-XPL)*SIN(TDIR)+(YPT-YPL)*COS(TDIR)
      Y=(XPT-XPL)*COS(TDIR)-(YPT-YPL)*SIN(TDIR)
C
      IF (X.GT.0.0) THEN
        TEMY=EXP(-0.5*(Y/AZMTH/X)**2)
        XTOTZ=0.0
        DO 10 N=1,NDROP
          TEMZ=EXP(-0.5*(3.0*(HEIGHT-XTERM(N)*X/SPEED)/AZMTH/X)**2)
          XTOTZ=XTOTZ+XFRAC(N)*TEMZ
10      CONTINUE
        XDEPO=QDT*TEMY*XTOTZ*HEIGHT/(2.0944*AZMTH*AZMTH*X*X*X)
      ELSE
        XDEPO=0.0
      ENDIF
      RETURN
      END

```

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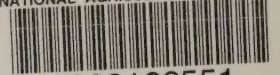
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